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Inventors: Vishwas G. Abhyankar, Victor C. Wong, Robert Breslawski,
Robert S. Jones, Badhri Narayan, Robert V. Reisch, Donald
R. Williams, Robert B. Bayley, Richard Weil and
Robert W. Duncan

Customer No. 01333

**A METHOD OF DECODING DATA ENCODED IN A
MONOCHROME MEDIUM**

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**A METHOD OF DECODING DATA ENCODED IN A MONOCHROME
MEDIUM**

CROSS REFERENCE TO RELATED APPLICATIONS

Reference is made to commonly-assigned copending U.S. Patent
5 Application Serial No. 10/000,407, filed November 2, 2001, entitled DIGITAL
DATA PRESERVATION SYSTEM, by Wong et al.; and U.S. Patent Application
Serial No. 10/059,994, filed January 29, 2002, entitled A METHOD OF
ENCODING DATA IN A MONOCHROME MEDIA, by Abhyankar et al., the
disclosures of which are incorporated herein.

10 **FIELD OF THE INVENTION**

This invention generally relates to a method for long-term
preservation of data and more particularly relates to the decoding of data
preserved with an image on monochrome media.

BACKGROUND OF THE INVENTION

15 In spite of numerous advances in development and use of color
imaging media, there are a number of conditions in which monochrome imaging
media must be used. For example, archival or long-term preservation of images
may require that images be stored on a monochrome media. As another example,
there can be advantages to compact storage of images, where it is desirable to use
20 a monochrome media for preserving a color image, with accompanying encoded
information.

There can be a considerable amount of data associated with an
image, where the data concerns the image itself. For example, in printing
applications, information about an image can include color separation data for
25 corresponding cyan, magenta, yellow, and black (CMYK) inks or other colorants.
Typically, color separations can be stored as separate images on monochrome
media, so that each color separation is then stored as a separate monochrome
image. For example, U.S. Patent No. 5,335,082 (Sable) discloses an apparatus
using a plurality of monochrome images as separations of a composite color
30 image. Similarly, U.S. Patent No. 5,606,379 (Williams) discloses a method for
storing color images on a monochrome photographic recording medium in which
separate R, G, and B or lightness and chroma channels are stored as separate

images. Such methods may be acceptable for some types of storage environments; however, it can be appreciated that there would be advantages in storing fewer images and in providing a more compact arrangement.

A number of existing methods for encoding data associated with an image are directed to the problem of encoding color image information within a monochrome image. Examples of solutions for this type of image-data encoding include the following:

U.S. Patent No. 5,557,430 (Isemura et al.) discloses a method for processing a color image in order to encode color recognition data on a resulting monochrome image. The method described in U.S. Patent No. 5,557,430 provides some amount of color information available; however, such a method is usable only in limited applications, such as where only a few spot colors are used on a document, such as a business presentation.

U.S. Patent No. 5,701,401 (Harrington et al.) discloses a method for preserving the color intent of an image when the image is printed on a monochrome printer. Distinctive patterns are applied for each color area.

U.S. Patent No. 6,179,485 (Harrington) discloses a method for encoding color information in monochromatic format using variously stroked patterns. This method is primarily directed to preserving color intent for fonts and vector (line) drawings.

Similarly, U.S. Patent No. 6,169,607 (also to Harrington) discloses methods for encoding color data in monochrome text using combinations of bold, outline, and fill pattern effects.

U.S. Patent Nos. 4,688,031 and 4,703,318 (both to Haggerty) disclose methods for monochromatic representation of color using background and foreground patterns.

Overall, the methods disclosed in U.S. Patent Nos. 5,557,430; 5,701,401; 6,179,485; 4,688,031; and 4,703,318 may provide some color encoding that is useful for documents using a very limited color palette, such as

business documents and charts. However, these methods would be unworkable for a full-color image, where the need for a pixel-by-pixel encoding would require considerably greater spatial resolution than these methods provide. At best, such methods may be able to provide a rudimentary approximation of color using relative lightness levels. However, there is no provision in any of the schemes given in the patents listed above for encoding of additional data related to the color image when it is represented in monochrome format.

Known methods used for encoding data associated with an image include that disclosed in U.S. Patent No. 5,818,966 (Prasad et al.), which discloses encoding color information along a sidebar that prints with a monochrome version of a document. This solution would have only limited value, such as with charts and other business graphics using a palette having a few colors.

Each of the solutions noted above is directed to encoding data about the image itself, such as color data. However, it may be useful to encode other types of data that, although not directly concerned with image representation itself, may be associated with an image. For example, an image can have associated audio data, animation data, measurement data, text, or other data, where it is advantageous to have such data coupled in some manner with the image. Use of a sidebar, such as disclosed in U.S. Patent No. 5,818,966 provides some solution; however, such a solution requires additional media area that may not be inherently coupled to an image. Because most images are stored in a rectangular format, any additional patch of information must be stored above, below, or on either side of the image. Accompanying information would take up additional space on the media. In addition, any encoded information provided in a separate area of the storage medium could be intentionally or unintentionally separated from the image itself.

Methods for encoding data in visible form on a monochromatic medium include the following:

U.S. Patent No. 5,091,966 (Bloomberg et al.) discloses the use of monochromatic glyph codes encoded onto a document image, in visual juxtaposition to the image. Notably, the area

in which the glyph codes are encoded is separate from the document image itself with this solution.

U.S. Patent Nos. 6,098,882 (Antognini et al.) and 4,939,354 (Priddy et al.) disclose methods for encoding digital data onto paper in compact form using bi-tonal markings grouped in a spatial array of cells. The ability to provide increasingly more compact data storage on monochrome media, using methods such as those disclosed in U.S. Patents No. 6,098,882 and 4,939,354, can be attributed, in large part, to continuing improvement in the spatial resolution of desktop scanners.

U.S. Patent No. 5,278,400 (Appel) discloses a method for encoding data in a cell comprising multiple pixels, where the halftone gray level of each individual pixel, in combination with other pixels within the cell, encodes a data value for the cell. The method disclosed in U.S. Patent No. 5,278,400 also takes advantage of increased spatial resolution of scanners, supplemented by the capability of a scanner to sense gray level at an individual pixel within a cell.

The methods disclosed in U.S. Patent Nos. 5,278,400, 6,098,882, and 4,939,354 provide data encoding for compact data storage on a monochrome medium. However, neither these methods nor the methods disclosed in the patents cited above provide a mechanism for integrally coupling data to an associated image. These methods also require space on the monochrome medium, in addition to that required for the image itself.

Some types of monochrome media, such as paper, for example, allow reproduction of only a limited range of perceptible densities. That is, only a few different density levels can be reliably printed or scanned from such types of media. However, there are other types of monochrome media that have pronouncedly greater sensitivity. Conventional black and white photography film, for example, is able to faithfully and controllably reproduce hundreds of different gray levels, each measurably distinct. Other specialized films and photosensitive media have been developed that exhibit wider overall dynamic range and higher

degrees of resolvable density, able to produce a higher number of distinct grayscale values.

It is instructive to observe that the term "grayscale" is conventionally associated with a range of densities where the monochromatic color hue is black. However, for the purposes of this application, the monochromatic color hue, or color base, for a grayscale image need not be black, but could be some other color. For example, some types of monochrome film have a very dark blue color hue that could be used as the color base for grayscale imaging. Regardless of the precise color hue, the term "grayscale" as used herein relates to a range of measurable density values of a single base color, formed at individual pixel locations on a digital preservation medium.

It is instructive to note that the human viewer perceives only a limited number of grayscale gradation values, centered on a range that is well within the overall dynamic range of most types of photosensitive media. Generally, a bit depth of 8-bits is sufficient for storing the grayscale values perceptible in monochrome images. While, for human perception, there may be no need for visible representation exceeding a bit depth of 8-bits, it could be possible to reproduce an image having a larger bit depth, with 10, 12, or greater bits of resolution, for example, using photosensitive media described above. In fact, many conventional scanners have additional sensitivity for grayscale resolution. The four-color printing industry, for example, uses high-resolution color scanners that are able to provide very high spatial resolution and very sensitive color resolution. As just one example, the SG-8060P MarkII High-end Input Scanner from Dainippon Screen claims to be capable of scanning at 12,000 dpi and providing 48-bit RGB resolution. Anticipated improvements in scanning technology are expected to make the capability for such high resolution and high density sensitivity more readily accessible and more affordable. This would mean, for example, that a scanner could have sufficient sensitivity to provide data with a bit depth exceeding 8-bits when scanning a highly sensitive media, even though 8-bit grayscale representation is sufficient for storing an image in human-readable form.

Conventionally, in converting a full-color image to a monochrome format only the relative lightness or darkness value of a color is used to determine a corresponding grayscale representation. Chroma information, which indicates color hue content, is largely ignored. For this reason, restoration of original color information to an image, once converted to monochrome format, is not easily feasible. It can be appreciated that image storage solutions that preserved some color information, even if approximate, could be advantageous.

Thus it can be seen that conventional document storage and preservation solutions fall far short of meeting the need to integrally couple data related to an image to the image itself. Even though the capability exists for reproducing and measuring image density sensitivity well in excess of the human-perceptible range, no use has been made of this excess capability for its data storage potential.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method of decoding, from a rasterized image formed on a monochrome medium, a plurality of data values encoded within each pixel, the method comprising, for said each pixel, the steps of:

- (a) scanning said each pixel to obtain a monochrome density value having a predetermined bit depth;
- (b) decomposing said monochrome density value to obtain a first data field and a second data field;
- (c) decoding said first data field in order to obtain a first data value; and
- (d) decoding said second data field in order to obtain a second data value.

It is a feature of the present invention that it allows a coupling of data associated with a document to the document itself, in such a way that the coupled, encoded data is not easily separable from the image of the document, but does not obscure the image. At the same time, the coupled data can be encoded in a manner that is imperceptible, while the document itself is visible. The method of the present invention allows a document and its associated encoded data to be

preserved on a monochrome preservation medium, available for future access and decoding.

The present invention takes advantage of the high levels of resolvability available with some types of monochromatic media. High-
5 resolvability allows encoding of data in gray levels, where the number of gray levels that can be reproduced and detected exceeds the number of distinct gray levels that can be distinguished by the human eye.

It is an advantage of the present invention that it provides a method for long-term preservation of a document and its associated data as a single unit.

10 It is yet a further advantage of the present invention that it provides a method for preserving, onto a monochrome medium, data about a full-color image. This includes, for example, tristimulus color data based on standard $L^*a^*b^*$ color space, on hue-saturation-brightness color space, on RGB color space, or on CMY color space.

15 It is yet a further advantage of the present invention that it provides a method for storing metadata associated with a document or with document image processing in a manner such that the metadata is closely coupled or, in some embodiments, integrally coupled to the document.

20 It is yet a further advantage of the present invention that it provides a method for storage of data having considerable density, yet without making existing equipment obsolete. That is, existing image sensing apparatus may not be able to take advantage of denser data encoding capabilities offered by the present invention, but can still be used for scanning an image preserved using these techniques, for example. For images, higher order density values typically store
25 the lightness channel information, so that, as a baseline, an image remains human-readable even if it contains considerable additional data content.

It is yet a further advantage of the present invention that it allows a provider of document preservation services to offer its customers variable levels of information decoding, so that only needed portions of encoded data are restored
30 in response to a customer request.

These and other objects, features, and advantages of the present invention will become apparent to those skilled in the art upon a reading of the

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following detailed description when taken in conjunction with the drawings wherein there is shown and described an illustrative embodiment of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

While the specification concludes with claims particularly pointing
5 out and distinctly claiming the subject matter of the present invention, it is believed that the invention will be better understood from the following description when taken in conjunction with the accompanying drawings, wherein:

Figure 1 is a block diagram showing an arrangement of
components used to preserve a document along with its associated encoded data;

10 Figure 2 is a flow chart illustrating key steps in processing for document preservation with associated encoded data;

Figure 3 is a visual representation of a data word having multiple data fields, each data field having a predetermined bit depth;

15 Figure 4 is a graph showing a typical relationship of density to the logarithm of exposure energy for a typical photosensitive medium, indicating separate density ranges of interest;

Figure 5 is a visual representation of a mapping operation for correlating data fields within a data word of a larger bit depth to data fields within an 8-bit byte;

20 Figure 6 is a visual representation of an 8-bit byte used in a mapping operation such as that illustrated in Figure 5;

Figure 7 is a plane view showing one possible layout arrangement for a preserved document record;

25 Figure 8 is a plane view showing a metadata record and calibration strip on a media roll;

Figure 9 is an example data listing for metadata information applicable to a media roll, cassette, or other unit;

Figures 10a through 10d show an example structure and data fields for metadata information applicable to a preserved document record;

30 Figure 11 is a flow chart illustrating key steps for decoding encoded data according to the present invention;

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Figure 12 is a block diagram showing an arrangement of components used to decode preserved document data that has been encoded in an image; and

Figure 13 is a visual representation of a monochrome data word having an additional data field in an alternate embodiment.

DETAILED DESCRIPTION OF THE INVENTION

The present description is directed in particular to elements forming part of, or cooperating more directly with, apparatus in accordance with the invention. It is to be understood that elements not specifically shown or described may take various forms well known to those skilled in the art.

Referring to Figure 1, there is shown a preservation system 80 for accepting an input document and its associated data, encoding the data, and writing the rasterized image and data encoding onto a monochrome preservation medium to generate a preserved document record 90. A control processing unit 88, typically a computer workstation, accepts an input document in electronic form from any of a number of possible sources. One input source could be a networked graphics workstation 82. Alternately, an input document could be from a printed page 84, photograph, or other printed image that can be converted to electronic form by a scanner 86. Other possible document sources could include, but are not limited to, digital camera images, Photo CD images, on-line image archives, computer-generated images such as from CAD and graphics design software packages and multimedia software packages, document processing systems, and imaging instruments, for example. Documents could include data files of many types, including web pages, spreadsheets, email, electronic files from programs such as Microsoft Word, PowerPoint, Excel, and the like.

Control processing unit 88 accepts the document data from any suitable source and formats image data into a rasterized form suitable for a printer 92. In rasterized form, the document is converted into one or more images. Each rasterized image comprises a two-dimensional array of pixels, with each pixel having an assigned value, such as a tristimulus color value, for example. In addition, control processing unit 88 may also format, encode, and rasterize

additional data or metadata to be associated with the document and to be imaged along with the document onto preserved image record 90. This additional data or metadata may be provided by software that executes on control processing unit 88 itself or may be provided from graphics workstation 82 or from some other data source. This data or metadata could include information entered by a user or customer of preservation system 80.

Monochrome Preservation Media for Images and Encoded Data

Examples of suitable human-readable preservation media for imaging by preservation system 80 include microfilm and related film products and other types of media having similar long-life expectancy and excellent image stability. In addition to film-based media, some other media types that may be acceptable, in some form, for use as human-readable preservation media include the following:

- (a) electrophotographic media, when properly treated and finished;
- (b) thermal media, such as thermal dye sublimation media;
- (c) inkjet media, particularly using plastic film or reflective materials; and
- (d) metal plate materials, written using methods such as etching and laser ablation.

The materials that are used for human-readable preservation media are characterized by exceptionally long useful life. This is in contrast to conventional binary storage media, such as magnetic tapes or disks or optical storage media. These conventional media types are not readable to the human eye, whether aided by magnification or unaided, and are not suitable for reliable long-term data storage due to their relatively short lifespan and due to hardware and software dependencies for data access from these media. For example, changes to operating system, CPU, or application software can render data that has been recorded on binary storage media to be unusable. By contrast, data recorded in human-readable form on preservation media can still be interpreted, regardless of changes to CPU, operating system, or application software.

Preservation media are typically packaged and provided in some form capable of holding multiple records or frames. Typical formats include roll, cassette, or cartridge format. Preferably, the preservation medium exhibits a sufficient, controlled dynamic range that allows representation of many more individual grayscale levels than are distinguishable to the human eye. The potential excess capability of high-quality monochrome media, such as, for example, KODAK Film SO-240 produced by Eastman Kodak Company, Rochester, New York, makes it possible to utilize media of this type for encoding, into image pixels, related data that is associated with that image.

10 Stages in Document Processing

As the above description suggests, any of a number of types of data, including metadata, can be encoded for preservation on a monochrome medium along with the rasterized image of a document. A few of the numerous types of data that might commonly be preserved with an image include color data, audio, measurement, and animation data, for example. For the purpose of initial description, the processing sequence for preservation of document data that is described with reference to Figures 2 through 11 below uses, as an illustrative example, the encoding and preservation of tristimulus color data associated with an image document. Following the description for this type of encoding, the discussion of this specification then broadens its scope to encompass more general cases of encoding and decoding associated data.

Referring then to the flow chart of Figure 2, there is shown a processing sequence for encoding document data to a monochrome medium. As was described above, an input file in electronic form is provided to this process; in the preferred embodiment, the input file includes a color image. A rasterization step 200 formats the input file to a rasterized, pixel format, where each pixel has an associated raster value. In the preferred embodiment, this raster value is a tristimulus color image value using CIELAB color space, with component values of lightness (L^*), a-chroma (a^*) and b-chroma (b^*). A counter initialization step 202 and a counter increment step 204 are provided to illustrate the mechanics of looping operation for processing each image pixel. For each pixel, a monochrome word assignment step 206 assigns a word for storing encoded values for grayscale

representation. The assigned monochrome data word has a predetermined bit depth that is a factor of the density resolution of the preservation medium, the density-marking characteristics of printer 92, and the performance characteristics of an intended scanning device for scanning and extracting encoded data at some future time. The data word is itself partitioned into a first data field, a second data field, and possible third and subsequent data fields. In the preferred embodiment, the monochrome data word has first, second, and third data fields for encoding lightness, a-chroma, and b-chroma values respectively. For each pixel an encoding step 208 is then executed. In encoding step 208, the first component value, lightness L^* in the preferred embodiment, is encoded in a first data field of the monochrome data word. A second value is then encoded in a second data field of the monochrome data word. This is the a-chroma value a^* in the preferred embodiment. The b-chroma value b^* is then encoded in a third data field of the monochrome data word in the preferred embodiment. However, other types of data could alternately be encoded into the second, third, and subsequent data fields as part of encoding step 208. A number of data representation schemes can be employed for encoding additional values to additional data fields of the monochrome data word. At the conclusion of encoding step 208, a grayscale forming step 210 is then executed. In grayscale forming step 210, the various data fields in the monochrome data word are used to generate a grayscale value for imaging the pixel. The monochrome data word can be used without any modification; alternately, its fields can be concatenated or otherwise combined in some other order. In an imaging step 212, then, the pixel can be formed by printer 90 with the intended grayscale value generated in grayscale forming step 210. Finally, a looping decision step 214 determines whether or not each pixel has been assigned its grayscale value.

Those skilled in the computing arts can readily recognize that the flow chart of Figure 2 illustrates only one possible implementation of image encoding and printing using a loop, using the mechanics of steps 202, 204, and 214. Alternate logic flow sequences could be used. In practice, imaging step 212 would most likely write the data for pixel_n into an intermediate memory buffer or similar structure, so that a complete image could be sent to printer 90 at one time.

Regardless of the exact processing mechanics, however, the basic assignment and value mapping scheme outlined in steps 200, 206, 208, and 210 of Figure 2 would be carried out in some fashion in order to implement the method of the present invention.

5 As shown in Figure 3, for most standard tristimulus color imaging, the input file is encoded in a 24-bit raster value 100. A preprocessing step may be needed to convert color image data into a suitable format such as that represented in Figure 3. One common color image format uses the familiar CIE 1976 $L^*a^*b^*$ or CIELAB color space of the CIE, Commission Internationale de l'Eclairage
10 (International Commission on Illumination), well known to those skilled in the color imaging arts. For the CIELAB format, there are three channels of information: lightness (L^*), a-chroma (a^*) and b-chroma (b^*). Each channel of information uses 8-bits, so that a complete 24-bit word is needed to express the CIELAB $L^*a^*b^*$ color space value of each image pixel, as was shown in Figure 3.
15 Raster value 100 as shown in Figure 3 has a bit depth of 24 bits with 3 data components. A first data component 104 contains the L^* channel value. A second data component 106 contains the a^* channel value. A third data component 108 contains the b^* channel value.

 Ideally, it would be advantageous to be able to store each 24 bit
20 CIELAB $L^*a^*b^*$ value for each pixel. However, there are two practical considerations that underlie the implementation of the encoding scheme that follows:

(1) limitations of the monochrome media. While it may be theoretically possible to accurately reproduce 10-, 12-, 14-bits
25 or greater resolution on a monochrome medium, existing media and imaging techniques would make it very difficult to approach the 24-bit resolution that would be needed for full, lossless encoding.

(2) limitations of human perception. With respect to
30 monochrome imaging, the human eye is sensitive to a limited number of grayscale monochrome gradations. In practice, as few as 16 different grayscale levels provide monochrome

representations of color images that are considered visually accurate and pleasing.

As the graph of Figure 4 shows for a typical photosensitive medium, the density response can be segmented into three overall regions. The human eye is most sensitive over a high contrast region 124. The photosensitive medium also exhibits density response over a shoulder region 122 and a toe region 126, however, human perception is not highly sensitive within these high and low extremes. In conventional tristimulus color-to-monochrome mapping schemes, only high-contrast region 124 is used, and typically only for mapping to a corresponding lightness channel value.

In light of these considerations, then, encoding step 208 of the present invention (Figure 2) performs a mapping from the 24 bit $L^*a^*b^*$ color space representation of raster value 100 to an 8-bit byte that serves as a monochrome data word 120. Referring to Figure 5, there is shown the mapping scheme from raster value 100 to monochrome data word 120 as used in a preferred embodiment. The 8-bit value in first data component 104, containing the L^* value, is mapped to a first data field 114, which contains 4 bits. This mapping enables as many as 16 discrete grayscale levels to be represented for the lightness values of pixels in the original color image. The 8-bit value in second data component 106, containing the a^* value, is mapped to a second data field 116, which contains 2 bits. Similarly, the 8-bit value in third data component 108, containing the b^* value, is mapped to a third data field 118, which also contains 2 bits.

For mapping of components 104, 106, and 108 to data fields 114, 116, and 118 respectively, a number of methods can be used. In the preferred embodiment, mapping is performed using a straightforward histogram and statistical techniques for mapping a large set of multiple values to a smaller set of representative key values, where each key value allows a reasonable approximation of a set of nearby larger values. For example, for actual image data values ranging from 18 to 23, a representative key value 20 may be chosen. Further encoding processes may then map key value 20 to an integer value that can be represented using 2 or 4 bits. Such statistical and mapping techniques,

familiar in the data processing arts, enable effective "compression" of image data so that some amount of color data that may have been originally obtained at 8-bit resolution can be preserved in a 2-bit or 4-bit data field of monochrome data word 120.

5 In the preferred embodiment, as is shown in Figure 5, the 2 bits for each a^* value, and the 2 bits for each b^* value in monochrome data word 120 allow the mapping of corresponding 8-bit chroma values to the appropriate one of the indexed a^* and b^* chroma values. Similarly, using 4 bits for the L^* value allows mapping of an 8-bit lightness value to an appropriate indexed value with
10 higher resolution.

Returning back to Figure 2, grayscale forming step 210 may be no more complicated than simply using, as the grayscale value, all data fields 114, 116, and 118 in monochrome data word 120, plus any additional data fields into which monochrome data word 120 is partitioned. Optionally, depending on the
15 available monochrome density resolution, customer requirements, or other factors, only individual data fields 114, 116, 118 may be used or fields 114, 116, and 118 may be concatenated in any suitable combination.

The procedure of Figure 2 is executed for all pixels in the rasterized document. Note that the monochrome image that prints as a result of
20 the process described above with reference to Figure 2 may have the same overall appearance as a monochrome image produced from a color image by using only the lightness L^* channel information. However, unlike conventional methods that use a relative lightness value and preserve no chroma information, the method of the present invention allows an indexed lightness value to be represented and
25 preserves chroma information in the lower 4 bits of the 8-bit grayscale value. Since the lower 4 bits are not readily perceptible to the human observer, the information stored in these bits does not interfere with the overall appearance of the preserved image; however, scanning the preserved image with a high-resolution scanning device will allow the encoding of the lower 4 bits to be
30 retrieved.

Metadata about the Document

In addition to pixel grayscale values, there may be more information needed for re-creation of the original full-color image or needed for accompanying the image itself. Referring to Figure 7, there is shown an encoded image 96 on preserved document record 90. Below image 96 is a document metadata section 94. Document metadata section 94 provides, in human-readable form, necessary information for interpreting the document data in encoded image 96. Information in data fields of document metadata section 94 could include any of the following, for example:

- (a) key values or values that occur most frequently;
- (b) color space parameters or pointers to a color palette;
- (c) metadata on bit and data field assignment for grayscale values;
- (d) data field concatenation scheme used;
- (e) data field mapping scheme used;
- (f) image spatial resolution, typically in dots-per-inch (dpi), and length and number of scan lines; and
- (g) bit depth of grayscale pixels.

Registration marks 98 are provided as reference targets for use of scanner 86 in precisely locating document metadata section 94 and encoded image 96 on preserved document record 90 during decoding, as described subsequently.

Referring to Figures 10a through 10d, there is shown an example of the human-readable data provided in document metadata section 94. It must be emphasized that Figures 10a through 10d are provided for example only, to illustrate some of the types of information that can be provided and one possible encoding scheme. In actual practice, the metadata that is provided in human-readable form is designed to best suit individual requirements of a data preservation application.

In general, the metadata fields must be written in human-readable format. Text characters are typically used for encoding in a data format that is open, extensible, and self-defining, such as XML (Extensible Markup Language), for example. This human-readability allows portions of the document to be

scanned and automatically interpreted, for example, using scanner 86 with tools such as Optical Character Recognition (OCR).

Figure 10a shows the overall structure of document metadata section 94 in a preferred embodiment. Encoded using XML, document metadata section 94 includes a header section 94h, followed by color channel sections 94c1, 94c2, and 94c3, one for each $L^*a^*b^*$ color channel. A terminating trailer section 94t denotes the end of the file for metadata section 94. Figures 10b, 10c and 10d then show metadata fields for color channel sections 94c1, 94c2, and 94c3 respectively. Each color channel section 94c1, 94c2 and 94c3 gives information on bit positions used for encoding color channel data, on value ranges, and on mapping definitions for encoding and decoding values. Ellipses (...) indicate where lines have been removed for simplifying and abbreviating Figures 10a and 10b.

By way of illustration, Figure 10b shows how lightness L^* values from 0 to 100 can be mapped to integers from 0 to 15, allowing the L^* data to be encoded in a 4-bit data field 114. In the third mapping definition given, for example, minimum and maximum boundary values are listed as follows:

`<Channel_Value min="12" max="17">`

Following this boundary value listing, an encoded value from 0-15 is defined for the range, as follows:

`<Encoded_Value>2</Encoded_Value>`

Then, a value for decoding is provided, showing the value that will be assigned, from the original range of 0 to 100, upon decoding of the encoded value, using the processing sequence described subsequently:

`<Decode_Value>12</Decode_Value>`

From this simple, partial illustration, it can be seen that, for an image encoded using this mapping method, values originally in the range 12-17 will be represented as value 12 when the document image is decoded and restored. There will be some loss of image quality; however, by selecting the mapping ranges carefully, a reasonably close approximation of the original document image can be preserved.

Metadata about the Media

Referring to Figure 8, media imaging characteristics must also be provided in order to decode encoded information from any image 96 on the media roll 190. In a preferred embodiment, the function of preserving media imaging characteristics is performed by assigning one or more separate media metadata documents 194 to document positions on media roll 190. Note that media roll 190 could be a roll of media or could be a cartridge, cassette, or other packaging unit. Information in media metadata document 194 that supports decoding operation could include any of the following, for example:

- (a) media calibration data or look-up tables; and
- (b) error-correction encoding information.

Registration marks 98 are provided as reference targets for use of scanner 86 in precisely locating media metadata document 194 and a calibration patch 196 on media roll 190 for decoding, as described subsequently.

In order for media metadata document 194 to be useful on any future hardware platform, the encoded data in media metadata document 194 must be in human-readable form. Referring to Figure 9, there is shown an example of a portion of the encoding of media metadata document 194 in the preferred embodiment. As shown in Figure 9, media metadata document 194 may include write and read calibration data for the preservation medium and characteristics for printer 92.

In addition to the media metadata and image metadata components listed above, there can be additional metadata that is associated with the roll, cartridge, cassette, or other unit in which the preservation medium is packaged. This metadata can be provided within media metadata document 194 and may include information on media type, aging characteristics, directory or document tracking data, and other information, for example.

Referring again to Figure 8, calibration patch 196 is also provided as part of the media metadata to allow calibration of a scanner for reading individual pixels of each image 96. In a preferred embodiment, calibration patch 196 is provided along with metadata section 194. A number of alternatives are possible, including having calibration patch 196 associated with the individual image 96 or with a group of images 96. Calibration patch 196 could be arranged

in a simple format, establishing sample or index points along a curve of non-linear density vs. code value or, where density is linear with respect to a range of code values, establishing end-points of a line or line segment. Calibration patch 196 could alternately include numeric annotation to label the intended data values
5 corresponding to one or more densities reproduced in the set of samples.

The contone image mapping method described above is somewhat lossy. That is, due to the approximation provided using histograms and statistical techniques, a color image that has been decoded and restored from its preserved document record 90 would not reproduce its original colors with precision in all
10 cases. However, extensions of the embodiment described above could be used to improve storage for chroma as well as for lightness channels. For example, with 12-bit resolution, data fields 114, 116, and 118 could be scaled to 3 or 4 bits, allowing additional gradation in chroma data as stored. With higher resolution, which means a larger bit depth, additional data could be encoded. The method of
15 the present invention can be practiced given any reasonably high resolution, with data fields assigned and organized accordingly. As a general principle, increasingly more robust arrangements are possible when larger bit depths become available.

Generalized Data Coupling to Document Image

20 The example outlined above with reference to Figures 2 through 7 was directed to the encoding of $L^*a^*b^*$ values in monochrome pixels. The same method could alternately be adapted for storing other types of information within grayscale levels, with selected data fields in any of a number of arrangements. With reference to Figure 6, for example, the visual appearance of an image could
25 be preserved using first data field 114 for grayscale representation, while using second and third data fields 116 and 118, whether separately or combined, for storage of alternate information. For example, by combining second and third data fields 116 and 118, monochrome data words 120 for successive pixels could be used to store a sequence of audio bytes, with each monochrome data word 120,
30 that is, each pixel; storing one half byte.

The mapping method of the preferred embodiment could be altered in a number of different ways within the scope of the present invention. For

example, it might be desired to arrange fields differently for mapping $L^*a^*b^*$ values. In a particular application, there may be no advantage in printing an image with accurate monochrome representation; in such a case, L^* values might be mapped to alternate fields within monochrome data word 120. Any arrangement of data fields could be used as an alternative to the structure shown in Figure 6. For example, third data field 118 or some additional data field could be assigned for image metadata, security information, authentication information such as a digital signature, error correction data, information about the overall document, or a reference to such information. The data stored in a data field could be encoded data or could be one part of a byte, word, or other data unit, where the individual parts of the data unit span multiple pixels. A data field could store data directly, or store a reference or pointer to data, such as a pointer to a color palette, for example. Fields in addition to data fields 114, 116, and 118 could be assigned, for encoding additional data to be preserved in preserved document record 90.

Encoding Data Using Shadows/Highlights Regions

Referring back to the density curve of Figure 4, it is instructive to observe that images are primarily represented using densities within high contrast region 124. In general, toe region 126, representing very low densities, and shoulder region 122, representing very high densities may be usable for data storage. This may mean using very dark or very light pixels within image 96 for storing encoded data, for example, where pixels above or below specific threshold densities are used primarily for data encoding.

Alternate Mapping Schemes

For preservation of color information, use of the CIELAB $L^*a^*b^*$ format is most favorable, since a lightness channel L^* value easily maps to a corresponding grayscale value. However, data representation formats other than the tristimulus CIELAB $L^*a^*b^*$ format of the preferred embodiment can be used. For example, color data could be stored in CIELUV format, where tristimulus values represent brightness, hue, and saturation. Alternately, color data could be encoded in tristimulus RGB format, CMY (Cyan, Magenta, Yellow) format or in CMYK format (with added Black component). Or, color data could be encoded in

a proprietary tristimulus data format, such as in KODAK Photo YCC Color Interchange Space, for example. In order to store all of the component values for the selected color space, the rasterized data values to be encoded would have a large bit depth, such as 24 or 32 bits in some cases. Monochrome data word 120, however, into which the components of tristimulus and other formats would be encoded, would have a small bit depth, such as the 8-bit monochrome data word 120 of Figure 6. The arrangement of fields within monochrome data word 120 can be freely adapted to suit the encoding requirements for color accuracy. As with the L^* channel information in the example of Figure 5, it may work best to map one component of color data using relatively more bits. For RGB color data, for example, it may be most effective to map green values to a 4-bit field, while mapping red and blue values, which may have less impact on some images, to smaller 2-bit fields. The values used in any field could be pointers to other values, such as the L^* , a^* , and b^* channel values in first, second, and third data fields 114, 116, and 118 of Figure 6. Or, these values could be sufficient in themselves, as might a 4-bit L^* channel value stored in first data field 114. Overall, the methods of the present invention as disclosed herein could be used for mapping any type of color representation data format from one data structure to another.

Images printed on preserved document record 90 could be positive or negative, with image density appropriately assigned for the preservation medium.

Depending on factors such as image type, spatial resolution, and data bit depth available due to density resolution, any number of alternate mapping schemes could be implemented, including the following:

- (a) use of "guard bits". Deliberate assignment of guard bits as separators for data fields may help to more clearly distinguish encoded data values; and
- (b) use of neighboring values and relative offsets. A number of data representation schemes can be employed that extrapolate image values for a pixel from those of neighboring pixels or that provide only offsets from an averaged value.

Decoding Process

As is true for data decoding in general, the procedure for extracting encoded data is the inverse of the corresponding procedure used to encode the data. Referring to the flow chart of Figure 11, there is shown a processing sequence for decoding data that has been encoded onto a monochrome medium to form image 96 having m pixels, using the method of the present invention.

Referring to Figure 12, the process of Figure 11 uses scanner 86 for obtaining data from preserved document 90 and for obtaining any necessary supporting calibration and media-specific metadata from media roll 190. In a setup step 300, scanner 86 is used to obtain encoding parameters for use in decoding by control processing unit 88. The necessary parameters include those provided in metadata section 94, media metadata document 194, and calibration patch 196. For dimensionally locating metadata section 94, media metadata document 194, and calibration patch 196 to be scanned using scanner 86, registration marks 98 or some other optical or mechanical locating means are used. For example, mechanical indexing means could be provided, allowing scanner 86 to pinpoint the precise location of metadata section 94. Human-readable content in metadata section 94, in media metadata document 194, and in labeling for calibration patch 196 allow flexible options for accessing the setup data that is needed. While automatic scanning and interpretation using OCR utilities is preferred, even manual interpretation and entry of the necessary setup data for setup step 300 is possible, because metadata is provided in human-readable format. Within the data itself, specific fields provide registration markings that clearly delineate the beginning of each block of data. For example, an identifying preamble clearly marks the starting-point for the first field of metadata in metadata section 94. As a result of setup step 300, scanner 86 and control processing unit 88 have sufficient information to obtain the encoded information from image 96 and to perform the processing of subsequent steps in Figure 11 for extracting the encoded data values.

A counter initialization step 302 and a counter increment step 304 are provided to illustrate the mechanics of looping operation for processing each of m image pixels. For each pixel n , a grayscale read step 306 receives a grayscale value, `grayscale_valuen`, from the scanner and stores this value in a data

word, monochrome_word_n, which has sufficient bit depth for storing the grayscale value. Then, in a data field restoration step 308, a plurality of data fields are extracted from monochrome_word_n. In this step, then, monochrome_word_n is decomposed into its component fields. As was described with reference to Figure 5, a preferred embodiment of the present invention encodes three data fields 114, 116, and 118 into monochrome data word 120. Then, to reverse the mapping operation shown in the example of Figure 5, an inverse mapping operation is executed to obtain, from monochrome data word 120, a composite raster value 100 or other decoded composite data value or set of data values, based on the encoding scheme that was used. In the preferred embodiment, this composite data value is a tristimulus color image value using CIELAB color space, with component values of lightness (L^*), a-chroma (a^*) and b-chroma (b^*). Finally, a looping decision step 310 determines whether or not each pixel has been scanned and its corresponding data processed.

Once all pixels have been scanned and all data values extracted, it is then possible to reconstruct the original encoded document, and any data coupled to the document, from the data obtained. As was noted above, the encoding may or may not be lossy.

Those skilled in the computing arts can readily recognize that the flow chart of Figure 11 illustrates only one possible implementation of image decoding for each pixel using a loop that utilizes the mechanics of steps 302, 304, and 310. Alternate logic flow sequences could be used. In practice, grayscale read step 306 would most likely read the grayscale value for some group of pixels or for all pixels in one operation, with the operations of data field restoration step 308 performed once all pixels have been read. Monochrome_data_word_n provides a convenient data structure for the sake of the example of Figure 11; however, a temporary register or other suitable structure could be used. Regardless of the exact processing mechanics, however, the basic data access and value extraction assignment and inverse mapping scheme outlined in steps 300, 306, and 308 of Figure 11 would be carried out in some fashion in order to implement the method of the present invention. The resulting data values obtained using the decoding

process could then be printed, displayed, stored, or used as input for further processing, for example.

Those skilled in the art of encoding and decoding information will also observe that additional supporting steps could be provided to optimize the basic procedure illustrated in Figure 11. For example, it may be useful to preprocess scanned image data in order to minimize the impact of noise, such as might be due to dust or scratches. Similarly, error checking and correction algorithms could also be applied in order to improve the accuracy of the scanned data obtained.

It can be appreciated that the method of the present invention allows a flexible procedure for extracting data encoded within image pixels in a monochrome medium. The method of the present invention allows compact data storage that integrally couples data to an image and provides suitable techniques for obtaining and decoding the stored data at some time in the near or distant future.

Variable Levels of Data Encoding and Decoding

The method of the present invention also allows a provider of document preservation services the flexibility to offer variable levels of data encoding and decoding. For example, it may be desirable initially to encode a substantial amount of information with an image, using a relatively large bit depth with multiple fields. Then, in response to standard requests for decoding, it may be sufficient to provide only some of the data fields stored. Thus, for example, different levels of decoding could be made available, at different cost for each level of decoding request. As one example, referring to Figure 13, an image could be encoded with data at a bit level of 12 bits. Monochrome data word 120 might then comprise four data fields, with data encoded as follows:

first data field 114, containing encoded L^* value in 4 bits;
second data field 116, containing encoded a^* value in 2 bits;
third data field 118, containing encoded b^* value in 2 bits; and
a fourth data field 119, containing encoded audio data value in 4 bits.

Then, using this model, the following levels of decoding could be available:

- (a) a first level of decoding, in which only the luminance channel L^* value from first data field 114 is provided;
- (b) a second level of decoding, in which a decoded $L^*a^*b^*$ value from first, second, and third data fields 114, 116, and 118 are provided; and
- (c) a third level of decoding, in which the full $L^*a^*b^*$ value is provided plus the audio data value from fourth data field 119.

5

Of course, alternate data levels could be provided for extracting data from preserved document record 90 in any combination of fields, such as, for

10 example, decoding only the audio data value from fourth data field 119. In any case, it would be possible for a provider of digital preservation services to offer its subscribers varying levels of data record preservation, at different pricing, based on how much of the preserved information coupled with an image is needed. A

15 provider of digital preservation services could then utilize low-cost scanner 86 apparatus more effectively for responding to decoding requests that require only a portion of the image bit depth. Customer requests requiring the fully encoded data would then require scanners 86 having higher density resolvability levels.

The invention has been described in detail with particular reference

20 to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the scope of the invention. Therefore, what is provided is a method for decoding of data associated with an image on monochrome media.

PARTS LIST

- 80. Preservation system
- 82. Graphics workstation
- 84. Printed page
- 86. Scanner
- 88. Control processing unit
- 90. Preserved document record
- 92. Printer
- 94. Metadata section
- 96. Image
- 98. Registration mark
- 100. Raster value
- 104. First data component
- 106. Second data component
- 108. Third data component
- 114. First data field
- 116. Second data field
- 118. Third data field
- 119. Fourth data field
- 120. Monochrome data word
- 120'. Monochrome data word
- 122. Shoulder region
- 124. High-contrast region
- 126. Toe region
- 190. Media roll
- 194. Media metadata document
- 196. Calibration patch
- 200. Rasterization step
- 202. Counter initialization step
- 204. Counter increment step
- 206. Monochrome word assignment step
- 208. Encoding step

- 210. Grayscale forming step
- 212. Imaging step
- 214. Looping decision step
- 300. Setup step
- 302. Counter initialization step
- 304. Counter increment step
- 306. Grayscale read step
- 308. Data field restoration step
- 310. Looping decision step

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